Available online at www.sciencedirect.com
SCIENCE DIRECT
PHYSICS LETTERS B
Physics Letters B 618 (2005) 43–50
www.elsevier.com/locate/physletb

Low-lying resonance states in the ^{9}Be continuum

Y. Prezado [a], M.J.G. Borge [a,*], C.Aa. Diget [b], L.M. Fraile [a,c], B.R. Fulton [d], H.O.U. Fynbo [b], H.B. Jeppesen [b], B. Jonson [e], M. Meister [e], T. Nilsson [c,f], G. Nyman [e], K. Riisager [b], O. Tengblad [a], K. Wilhelmsen [e]

[a] *Instituto de Estructura de la Materia, CSIC, Serrano 113bis, E-28006 Madrid, Spain*
[b] *Institut for Fysik og Astronomi, Aarhus Universitet, DK-8000 Aarhus C, Denmark*
[c] *PH Department, CERN, CH-1211 Geneva 23, Switzerland*
[d] *Department of Physics, University of York, Heslington, United Kingdom*
[e] *Fundamental Fysik, Chalmers Tekniska Högskola, S-412 96 Göteborg, Sweden*
[f] *Institut für Kernphysik, Technische Universität Darmstadt, Schlossgartenstr. 9, D-64289 Darmstadt, Germany*

Received 20 March 2005; accepted 12 May 2005

Available online 24 May 2005

Editor: V. Metag

Abstract

Excited states in ^{9}Be from 2 to 9 MeV are studied via beta delayed particle emission from ^{9}Li. The broad overlapping particle unbound states are investigated using an extension of an experimental method developed for dealing with three-body decays of broad isolated levels. The results confirm the existence of a broad state at 5 MeV, with a width of 2 MeV. Angular correlations are used for firm spin determinations for this and other levels.

PACS: 23.40.Hc; 21.10.Hw; 27.20.+n

Keywords: Radioactivity ^{9}Li(β^{-}-decay) [from Ta(p, X)]; Measured β-delayed E_{α}; $\alpha\alpha$-coincidence; ^{9}Be deduced levels and spins; Partial decay branches

There has been significant progress in ab initio calculations applied to the structure of light nuclei, now reaching the lowest energy states for several spin-values in isobars with mass 9 and 10 [1]. In particular, for ^{9}Be the lowest state for each spin up to $9/2$ has been calculated. This development presents a challenge for experimentalists to complete the knowledge on the excited states. This task gets increasingly harder as we move into the unbound parts of the spectrum. Even for a well studied stable nucleus such as ^{9}Be there are large uncertainties at about 5 MeV excitation energy. Ab initio calculations are not yet available

* Corresponding author.
E-mail address: borge@iem.cfmac.csic.es (M.J.G. Borge).

0370-2693 © 2005 Elsevier B.V. Open access under CC BY license.
doi:10.1016/j.physletb.2005.05.030

here. The different theoretical approaches, shell model [2,3], antisymmetrized molecular dynamics (AMD) model [4] as well as microscopic cluster models [5,6] predict more states than are seen experimentally. In particular all calculations coincide in predicting $3/2$, $5/2$ and $7/2$ states of negative parity in the region between 5–7 MeV excitation energy in ^{9}Be. So far only the first $7/2^-$ level at 6.38 ± 0.06 MeV has been firmly established, whereas candidates exist for a $3/2^-$ and $5/2^-$ level (see Refs. [7,8] and references therein).

All the levels in question have a width larger than 1 MeV. This, and the fact that they disintegrate into a three-particle $\alpha\alpha$n final state, makes it very difficult to determine their properties (the history of the equally wide $1/2^-$ state at 2.78 ± 0.12 MeV illustrates this point nicely [2]). We recently developed a new method whereby analysis of complete kinematics data of the three-body decay gave firm values for spin and parity of the mirror levels in ^{9}Be and ^{9}B at about 12 MeV with widths around 0.4 MeV [9,10]. We here report on an extension of this work to the broader and overlapping lower-lying states in ^{9}Be.

We note that the previous information on the tentative $3/2^-$ level at 5.6 ± 0.1 MeV is very limited. It has only been reported in a single experiment [11] where the broad level remained unresolved, and the spin assignment stems from theory. A possible mirror level in ^{9}B has been suggested in a recent analysis of beta-decay data of ^{9}C into ^{9}B done using multichannel, and multistate R-matrix approach [12], but the spin–parity assignment made there was $1/2^-$.

Apart from spin–parity assignments, the decay patterns of these broad levels can also be of interest. The properties of low-lying unbound states in ^{9}Be are relevant in the calculation of the $^4\mathrm{He}(\alpha\mathrm{n},\gamma)^9\mathrm{Be}$ reaction rate in the stellar scenario. In particular, the importance of the $^5\mathrm{He}+\alpha$ channel has been recently pointed out [5,12]. Thus a new experimental survey of the decay of the relevant states in ^{9}Be through the $^5\mathrm{He}+\alpha$ channel is needed and should be included in the evaluation of the stellar reaction rate as stressed in Ref. [13].

The experiment was carried out at the ISOLDE facility at CERN. The mass separated 20 keV ^{9}Li ion beam, produced by impinging an intense 1.4 GeV proton beam on a 32 g/cm^2 Ta-foil-target coupled to a surface ion source, was stopped in a 40 µg/cm^2 C-foil. The foil was situated in the centre of a detection system composed of two DSSSDs of 60 µm thickness with an effective dead layer of only 100 nm. The use of these detectors with ultrathin dead layers [14] in combination with the low energy of the ^{9}Li beam and the thin stopping C-foil have allowed us detection of alpha particles in coincidence with energies down to 300–350 keV. The singles α spectrum was measured later with a different setup consisting of a 40 µm thick Si-detector, placed at large distance to avoid summing. The solid angle subtended by this detector was 0.12% of 4π. The alpha particles could be separated from the noise at energies higher than 180 keV.

The experimental set-up used did not allow direct detection of the neutrons, but since the decay occurs at rest energy and momentum conservation allows us deduction of both its energy and direction. Therefore, the complete decay-kinematics can be reconstructed for coincidence events. In the left part of Fig. 1 the reconstructed data are shown. It has been found convenient to represent the data in the form of sum energy of the three particles versus the individual α_1, α_2, n energies. The observation of events along diagonals in the scatter plot indicates the presence of sequential decay through the different decay channels. The emission of the first particle from different states through the same intermediate state is thus denoted in this scatter plot by a diagonal as demonstrated in Ref. [15]. The diagonal with lowest slope (9/8) corresponds to the decay through the ^{8}Be(g.s.) channel, the next one with the same slope and higher energy offset to decays via the $^8\mathrm{Be}(2^+)$ state and the steepest one (9/5) to decays through the ^{5}He(g.s.) channel. This method to separate the contributions of the different channels is very important since as pointed out in [16] the calculated phase-space distribution of the two alpha particles in the three channels:

$$^9\mathrm{Be}^* \to \alpha + {}^5\mathrm{He}(3/2^-) \to \alpha + \mathrm{n} + \alpha,$$
$$^9\mathrm{Be}^* \to \mathrm{n} + {}^8\mathrm{Be}(2^+) \to n + \alpha + \alpha,$$

and direct $^9\mathrm{Be}^* \to \mathrm{n} + \alpha + \alpha$ are very similar. The right-hand side of Fig. 1 shows the low energy region of the scatter plot of E_{sum} versus α_1, α_2 and n. There is an increase of beta feeding at low energy corresponding to the contribution of the 2.43 MeV $(5/2^-)$ state $E(^9\mathrm{Be}^*) = E_{\mathrm{sum}} + 1.57$ MeV (break-up energy). Along the diagonal, corresponding to the break-up through the ^{5}He(g.s.) channel, rather strong feeding

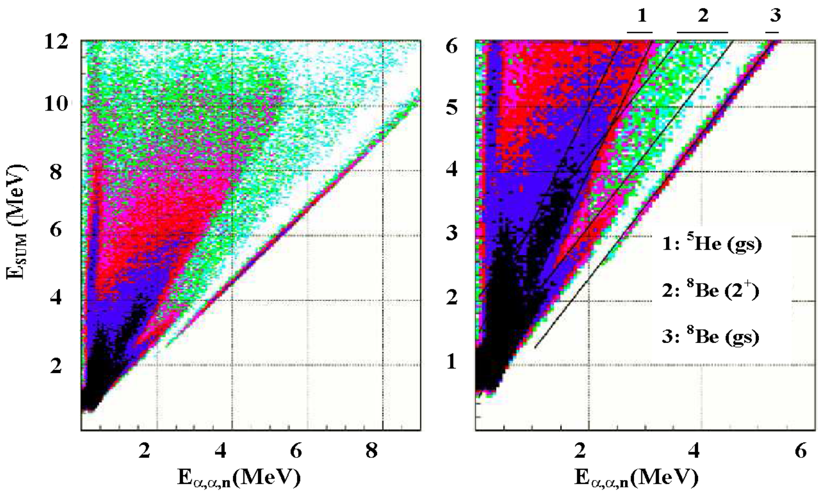

Fig. 1. Left: the deduced $\alpha + \alpha + \mathrm{n}$ sum energy is plotted versus the individual particle energies (E_{n} is deduced from momentum conservation). Right: blow-up of the scatter plot shown on the left. The continuous lines indicate the region where the first emitted particle goes: (1) via ^{5}He(g.s.) channel. (2) via ^{8}Be(2^+) or (3) via ^{8}Be(0^+). The width of the interval is given by the Γ of these intermediate states. An unexpected increase of strength is observed in the diagonal 1 between 3 and 4 MeV in sum energy along the ^{5}He(g.s.).

can be observed, but there is no report in the compilations [7,8] of such a decay branch.

First, let us here review what is known about the low energy states of negative parity in ^{9}Be i.e., the levels accessible in allowed beta transitions, and their decays. The energy, spin and decay modes of the narrow 2.43 MeV state in ^{9}Be are well known and the different experiments agree about the partial decay branch to the ^{8}Be(g.s.) giving a global average of $7 \pm 1\%$ [7]. The properties of the broad 2.78 MeV state are not so well known. The existence of a level at 2.78 MeV in ^{9}Be was found in the work of Chen et al. [17] by studying the β-delayed time-of-flight neutron spectrum. The spin of the state was assigned as $1/2^-$ since both the rotational model [18] and the shell model [3, 19] predicted a $1/2^-$ level around this excitation energy in ^{9}Be. The energy and width of the level have been confirmed in subsequent experiments [20–22]. Unfortunately, the partial decay branches of this broad level are more controversial as pointed out by Mikolas et al. [2] and summarized in their Table 2. In the original work of Ref. [17] it is stated that the 2.78 MeV level decays mainly to the ^{8}Be(g.s.). This conclusion is based on the reaction data [23] where neutrons coming from the excitation energy region 2.9–3.5 MeV were seen to feed the ^{8}Be(g.s.) with a branch of $87 \pm 13\%$. That work [23] was, however, based on the 3.049 ± 0.009 $5/2^+$ level in ^{9}Be. This statement therefore lacks experimental proof but it has anyhow been quoted in the literature [7,8]. From the assumption that the 2.78 MeV level decays mainly via the ^{8}Be(g.s.), a β-feeding of only 3% was found by Chen et al. [17] for this level. However, in the following β-decay experiment at CERN [21] an equivalent feeding was deduced for the 2.43 MeV level and the delayed alpha spectrum gave an additional 7% β-feeding to the 2.78 MeV state decaying to $\alpha\alpha$n through the ^{8}Be(2^+) and the ^{5}He(g.s.) states. The latter results have been confirmed by Nyman et al. [22] who carefully measured the low energy neutrons from the ^{9}Li decay giving a ratio of 2:1 for these two partial branches.

We have decided to check the decay of the 2.78 MeV state in our analysis, partly to resolve this question, partly to demonstrate that our method works also for very broad levels. The scatter plot indicates considerable intensity through the ^{5}He(g.s.) and ^{8}Be(2^+)-channels at low energy. To investigate this further we studied the angular distribution of the alphas which is sensitive to the spin of the states involved.

It is known that radiation or particles emitted in cascade by a nucleus are correlated in their relative direction of propagation. Biedenharn and Rose parametrized these correlations in Ref. [24]. In the present case, the states populated in allowed beta transitions

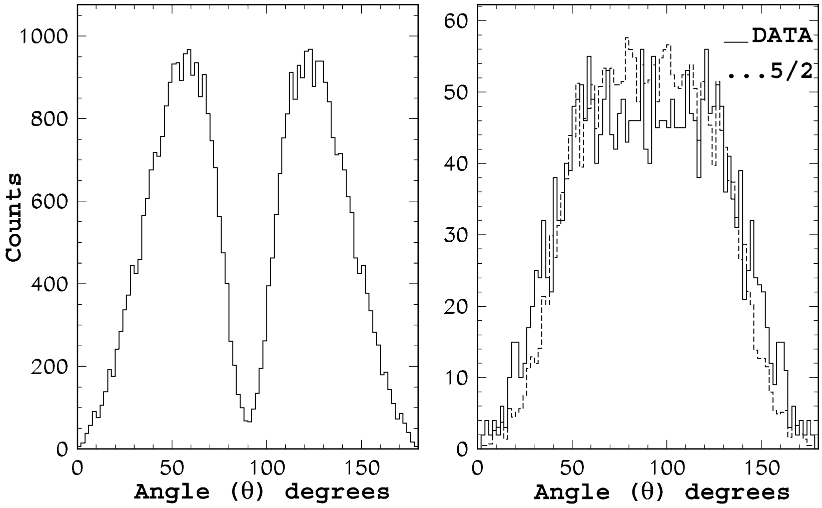

Fig. 2. Angular distribution of the data gating on the ^{5}He(g.s.) channel. Left: sum energy region 0.9 MeV $\leqslant E_{\mathrm{sum}} \leqslant$ 1.3 MeV. The angular distribution observed is typical of a $1/2$ state decaying by alpha emission to the ^{5}He(g.s.) Right: the angular distribution of the data in the $6 \leqslant E_{\mathrm{sum}} \leqslant 7$ MeV region (black line) is compared with the angular distribution coming from Monte Carlo simulations assuming a state at 7.9 MeV with a width of 1 MeV and a spin equal to $5/2^-$ (dashed line). The fit excludes the previous assignment of spin $1/2^-$ for the decaying level [7,21]. Our analysis strongly supports the tentative value given in the last compilation of Tilley et al. [8].

from the decay of ^{9}Li have spin and parity $1/2^-$, $3/2^-$ and $5/2^-$. The decay through the ^{5}He(g.s.) channel will be: $^9\mathrm{Be}^* \to \alpha + {}^5\mathrm{He}(3/2^-) \to \alpha + \mathrm{n} + \alpha$. Thus the angular correlation between the first emitted particle and the direction of the composite decay product (^{5}He) is given by the expression $1 + A_2(3\cos^2\theta - 1)/2$. The parameter A_2 very different for the three possible spins, allows the α–α angular distribution to trace the spin of the initial state in ^{9}Be. We have exploited this technique and studied different regions along the ^{5}He diagonal in Fig. 1. We first selected the region 0.9 MeV $\leqslant E_{\mathrm{sum}} \leqslant$ 1.3 MeV, along the diagonal 1 corresponding to the ^{5}He channel (see Fig. 1) in the decay of the 2.78 MeV state. The angular correlation between one alpha and the direction of the centre of mass of the $\mathrm{n} + \alpha$ system gives the distribution shown on the left part of Fig. 2. This is the typical distribution corresponding to an initial state of spin $1/2^-$ with a minimum at around 90° and two maxima at around 50° and 130°, respectively. We have thereby not only shown that there is a significant contribution of the break up of the 2.78 MeV state that does not feed the ^{8}Be(g.s.), but also obtained the first experimental evidence for the $1/2^-$ character of the 2.78 MeV state.

A small beta feeding to the 7.94 MeV state was proposed by Langevin et al. [21]. An analysis of the α–α angular distribution of the region of interest indicates that the spin of the initial state in ^{9}Be is not $1/2$ as suggested previously [7]. A spin of $5/2$ is deduced from the fit of the angular distributions for the different spins and the α–α correlation data. The data (continuous line) and the fit (broken line) are shown on the right-hand side of Fig. 2. This new spin value for the 7.94 MeV state is in agreement with the unpublished results of ^{10}B(e, e′p)^{9}Be [25] cited in the compilation of Tilley et al. [8]. One should, however, bear in mind that the feeding observed in this region might be due to the tail of the 11.8 MeV state.

Returning now to the central energy region (3 MeV $\leqslant E_{\mathrm{sum}} \leqslant$ 4 MeV), for the same selected channel the α–α angular distribution obtained is very different from the one observed for the 2.78 MeV state as shown on the left-hand side of Fig. 3. This angular distribution excludes spin $1/2$ for the initial state, and is fitted assuming spins $3/2$ (a-red line) and spin $5/2$ (b-blue line) for the decaying state in ^{9}Be through the ground state of ^{5}He. As shown in the figure our data favour spin $3/2$ for the initial state. Proton scattering studies of the structure of ^{9}Be [11] suggest a new level at 5.6(1) MeV excitation energy in ^{9}Be with a tentative spin–parity assignment of $3/2^-$. Such a level could be fed in beta decay, but before making any definite as-

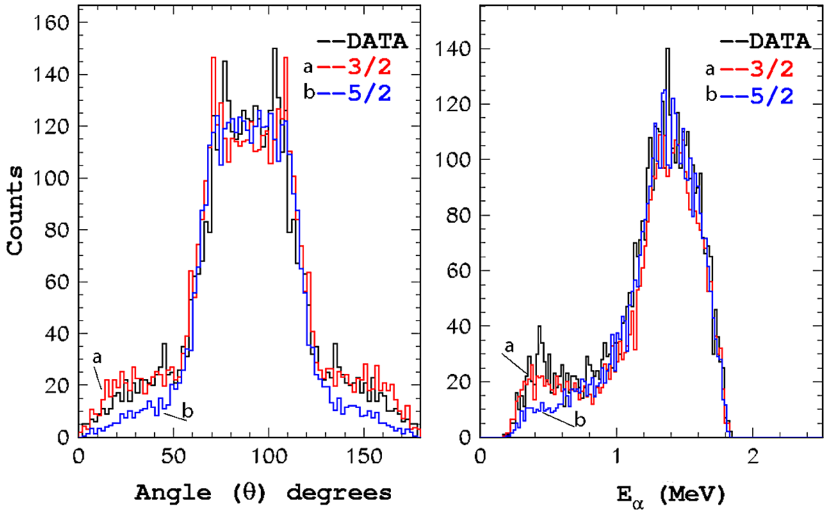

Fig. 3. Characterization of an unknown level from data gated on the ^{5}He(g.s.) channel between 3 MeV $\leqslant E_{sum} \leqslant$ 4 MeV. Left: the α–α angular distribution favoured spin 3/2 (a-red laine) for the state. Right: the alpha energy spectrum for events corresponding to the selected E_{sum} and with the most energetic alpha particle in the interval 1 MeV $\leqslant E_{\alpha 1} \leqslant$ 1.8 MeV. The α energy distribution is compared to Monte Carlo simulations assuming a level at 5 MeV with $\Gamma = 2$ MeV and spins equal to $5/2^-$ (b-blue line) and to $3/2^-$ (a-red line). The data consistently favours a spin–parity $3/2^-$ for the decaying level.

signments we shall investigate further whether the data require the contribution of a new level.

A projection of the α_1, α_2 spectrum has been fitted using the contribution of the previously known levels in ^{9}Be fed in the β-decay of ^{9}Li [21,22]: 2.43, 2.78, 7.9 and 11.8 MeV. We have performed Monte Carlo simulations to account for the different geometrical factors and thresholds of the particle detection in the different decay branches. The R-matrix formalism as explained in Appendix A of Ref. [22] was applied for the simulation of the primary and secondary decay branches. The position and width of the excited states were taken from [7,8]. A very detailed description of the method followed is given in [9]. The channel radii used in the R-matrix calculations were 6.2 fm for the ^{5}He(g.s.) and 6.1 fm for the ^{2}Be(2^+). For the decay of the excited states in ^{9}Be into these channels we have chosen channel radii of 4.2 fm and 4.5 fm for the more narrow and wider state, respectively. We do not include the 11.3 MeV state since it has been previously demonstrated [10] that it does not contribute significantly to the decay. Fig. 4 shows the comparison between the alpha spectrum obtained in coincidence data (black line) and a Monte Carlo simulation of the contributions of the breakup of the 2.43 MeV (a-green line), 2.78 MeV (b-dark blue line), 7.94 MeV (c-light blue line) and 11.81 MeV (d-red line) states. The contribution of the 2.43 MeV level was modelled using the prescription of Bochkarev et al. [26, p. 965]. The decay of the 2.78 MeV level through the ^{8}Be ground state could not be detected as the energies of the alphas from the breakup are below the threshold of the coincidence setup. Contributions from the ^{8}Be(2^+) and the ^{5}He(g.s.) channels are taken as 0.75 and 0.25, respectively. These values were obtained from the best fit to the singles spectrum. The 7.94 MeV level has been found to decay mainly through ^{5}He(g.s.) with 10% contribution to ^{8}Be(g.s.). Contributions from ^{8}Be(2^+) are found to be small (<20%). This is consistent with the intensity distribution seen in Fig. 1 for E_{sum} around 6 MeV. For the 11.8 MeV state the five decay branches with the relative values given in Table 1 of Ref. [10] have been considered. The contributions of the different $5/2^-$ levels at 2.43, 7.95 and 11.81 MeV have been added incoherently. As shown on the upper part of Fig. 4, the contributions from these levels are not sufficient to completely describe the projected α-spectrum. Their summed contribution is given by the e-fuchsia line of Fig. 4. When compared with the experimental α-spectrum, the simulation shows missing

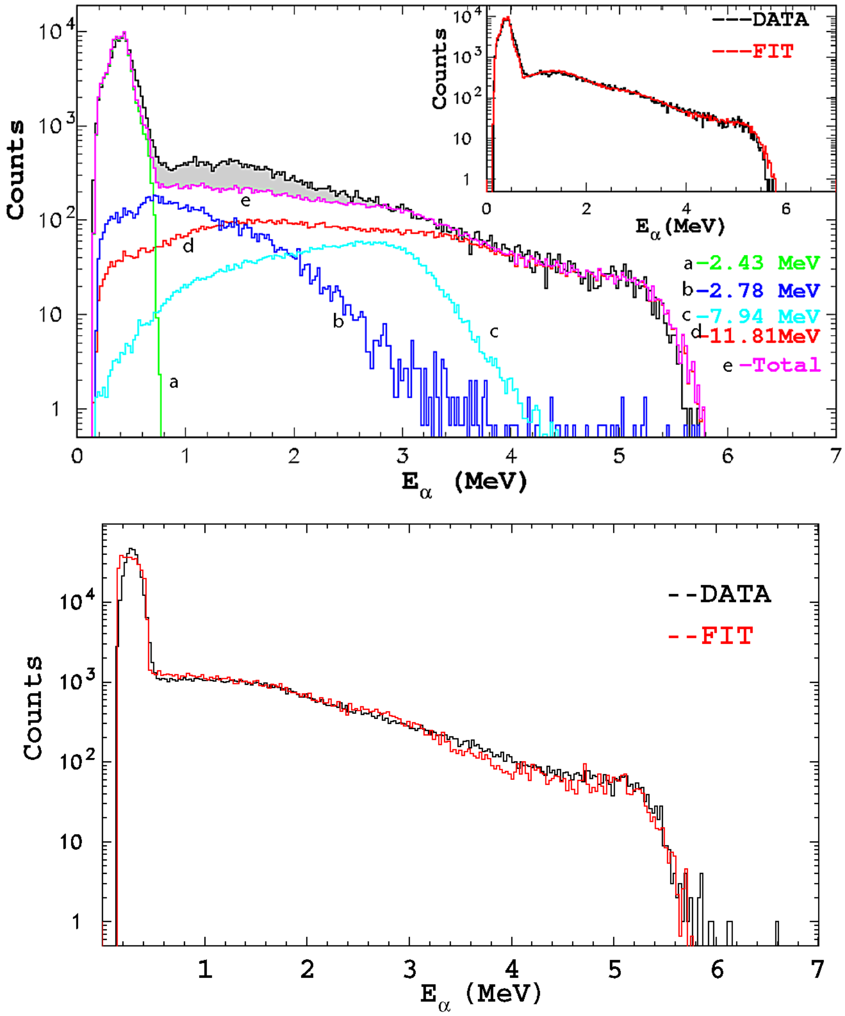

Fig. 4. On the top the known excited states at 2.43 MeV (a-green line), 2.78 MeV (b-dark blue line), 7.94 MeV (c-light blue line) and 11.81 MeV (d-red line) in ^{9}Be are used to fit the projected alpha spectrum obtained from coincidences (black line). The e-fuchsia line is the sum of the contributions of the simulations of the excited states in ^{9}Be. On the inset the same fit including the contribution of the new state at 5 MeV. On the bottom the fit of the singles alpha spectrum where the contribution of the known levels plus the 5 MeV one are included.

intensity in the region of the α-spectrum between 1–3 MeV, the difference indicated by the grey region in Fig. 4.

Consequently, we need to introduce a new level of spin 3/2 to completely reproduce the data. We shall deduce its properties in two different ways. First, by making use of the extra intensity observed in the scatter plot and, second, by looking at the projection of the alpha spectrum. To explain and characterize the intensity observed in the sum energy region between 3–4 MeV along the ^{5}He(g.s.) channel and trying to avoid the contribution from the 2.78 MeV state a region was selected to perform the data analysis with 3 MeV $\leqslant E_{\mathrm{sum}} \leqslant$ 4 MeV and restricting the α-particle with highest energy to a narrow area around the ^{5}He-diagonal, $1.8E_{\alpha 1} + 0.7 \leqslant E_{\mathrm{sum}} \leqslant 1.8E_{\alpha 1} + 1.1$ in MeV. The projected alpha spectrum was fitted using the R-matrix formalism assuming spin–parities of $3/2^{-}$ and $5/2^{-}$ for the initial state. On the right-hand side of Fig. 3 the selected alpha energy projection and the fits assuming $3/2^{-}$ (a-red line) and $5/2^{-}$ (b-blue line) for the spin–parity of the initial state are shown.

Table 1
Branching ratios of the beta-decay of ^{9}Li to the excited states of ^{9}Be

$E^*(^{9}\mathrm{Be})$ (MeV)	I^{π}	Γ (keV)	B.R. (%)			
			Coinc[a]	Singles	Ref. [21]	Ref. [22]
g.s.	$3/2^-$		49.2 ± 0.9[b]	49.2 ± 0.9[b]	50.5 ± 5	50 ± 3
2.43	$5/2^-$	0.77 ± 0.15	29.6 ± 1.3[c]	31.9 ± 3.4[c]	34 ± 4	30 ± 3
2.78	$1/2^-$	1080 ± 110	15.7 ± 0.8[d]	11.6 ± 2.2[d]	10 ± 2	16 ± 3
5.0	$3/2^-$	2000 ± 500	3.2 ± 1.0	3.15 ± 0.4		
7.94	$5/2^-$	≈ 1000	0.68 ± 0.12	1.5 ± 0.4	1.5 ± 0.5	< 2
11.81	$5/2^-$	400 ± 30	1.62 ± 0.07	2.7 ± 0.4	–[e]	2.7 ± 0.2[f]

[a] Error bars are purely statistical, a conservative estimate of the systematic error is 2–3%.
[b] Taken from Ref. [8].
[c] Calculated assuming that 7% of the total decay branch of the 2.43 MeV state decays via ^{8}Be(g.s.).
[d] Calculated assuming that 3% of the ^{9}Li β-decay goes to the 2.78 MeV state and decay via ^{8}Be(g.s.).
[e] A beta feeding of 4.0(9)% was assigned to the 11.28 MeV state.
[f] A beta feeding of 1.1(2)% was assigned to the 11.28 MeV state.

The best fit corresponds to a new state characterized by a spin–parity of $3/2^-$ at an energy of 5.0 ± 0.5 MeV and a width of 2.0 ± 0.5 MeV. The error bars give the limiting values for the centroid and width beyond which the fit deteriorates. The contribution of the different partial branches is deduced to be mainly through the ^{5}He(g.s.)-channel with a maximum of 10% for decay through the ^{8}Be(g.s.).

Including the contribution of this new level the fit of the projected coincidence alpha spectrum is shown on the inset of upper part of Fig. 4. On the lower part of Fig. 4 the fit to the singles data obtained with the 40 µm thick Si detector is shown. The beta branching ratios deduced in this fit are given in Table 1 and compared with previous values existing in the literature. Note that the branching ratio to the ^{9}Be ground state is now $49.2 \pm 0.9\%$ [8]. In the comparison with previous results we keep their normalization values for the β-feeding to the ground state as given in Table 1. We have two independent data sets from two different setups that agree nicely in the main branch to the narrow level at 2.43 MeV in ^{9}Be. The uncertainties in Table 1 are obtained from the width of the parabolic variation of the χ^2-distribution with each parameter. The decay of the 2.43 and 2.78 MeV states through the ^{8}Be(g.s.) channel could not be determined in this work since the α-particles from the break-up of ^{8}Be(g.s.) have too low energy to be detected in our setup.

The influence of the tail of the 11.8 MeV state at low energies induces systematic errors in the determined value of the beta-feeding of 1–2%. Therefore, at low energies it is very difficult to get reliable values for the beta-feeding. One should further bear in mind that a small systematic trend in the acceptance corrections could influence the extracted beta-feeding. Therefore, we recommend for the beta-feeding the values obtained from the singles analysis. One should also keep in mind that interferences among the states of equal spin–parity were not included in the R-matrix calculations.

The structure of ^{9}Be together with other isotopes of Be and odd mass isotopes of Li have been studied with the antisymmetrized molecular dynamics (AMD) model using three body interaction [4]. It predicts the three low energy levels in the right order ($3/2^-, 5/2^-, 1/2^-$) and three more with the same spins between 4 and 6 MeV. Shell model predictions of the $A = 9$ system within the p-shell have been summarized in the work of Mikolas et al. [2] who used the OXBASH code with four different interactions two from [3] and the other two from Ref. [27, 28]. Within the microscopic cluster model the resonance structure of ^{9}Be and ^{9}B has been investigated [5,6]. They calculate energy and width of the states as well as their spectroscopic factors for the decays via neutron to the ^{8}Be ground and first excited state and by alpha to ^{5}He($3/2^-$). Their calculations favour the latter channel for the states of higher spin. The best overall agreement with the experimental β-feeding values is obtained using the original (6-16)2BM2 interactions of Cohen and Kurath [3]. They predict a $3/2^-$ level with energy 5.09 MeV, with width around

1.5 MeV, and with equivalent spectroscopic factors to the $^{8}\mathrm{Be}(2^{+}) + \mathrm{n}$ and $\alpha + {}^{5}\mathrm{He}$ decay channels. A $5/2^{-}$ state is predicted at higher energy, 7.5 MeV, with similar ratios for the different channels. The excellent agreement of these calculations with our experimental results is remarkable.

Considering that ^{9}Be is a well studied nucleus, it is surprising, at first glance, that new information on states fed in beta-decay is found at such a low energy as 5 MeV. The incomplete knowledge is due to the low Z of the nucleus implying that the levels are very broad which leads to overlapping contributions in a single spectrum study. To make it worse one has a three particle final state with one of them beeing a neutron. The combined use of a selective and clean probe, the β-delayed particle emission of the short-lived nucleus ^{9}Li, and state of art detection set-up with essentially full kinematical coverage allowing for a complete characterization of the three-body final state.

It is striking that the determination of beta branching ratios to broad states is more demanding than determination of nuclear structure parameters of the states such as their spins, energies and widths. The reason is that the B_{GT} strength to a broad state is distributed over a large energy range due to the enhancement of the tail by the β-decay statistical rate function [9, 10].

The spin of $3/2^{-}$ deduced for the level at 5 MeV in ^{9}Be differs from the $1/2^{-}$ tentatively assigned in [12] as possible mirror level in ^{9}B. This underlines that even sophisticated fits to singles spectra are prone to systematic uncertainties when multi-particle continua are involved and that confirmation of spin assignments through angular distributions, as done here, are mandatory.

Acknowledgements

This work has been supported by the spanish CICYT, under the project FPA2002-04181-C04-02, and by the EU-RI3 (Integrated Infrastructure under Contract number 506065).

References

[1] S.C. Pieper, K. Varga, R.B. Wiringa, Phys. Rev. C 66 (2002) 044310.
[2] D. Mikolas, B.A. Brown, W. Benenson, L.H. Harwood, E. Kashy, J.A. Norle Jr., B. Sherill, J. Stevenson, J.S. Winfield, Z.Q. Xie, Phys. Rev. C 37 (1988) 766.
[3] S. Cohen, D. Kurath, Nucl. Phys. 73 (1965) 1.
[4] Y. Kanada-En'yo, H. Horiuchi, A. Ono, Phys. Rev. C 52 (1995) 628.
[5] P. Descouvemont, Eur. Phys. J. A 12 (2001) 413.
[6] K. Arai, P. Descouvemont, D. Baye, W.N. Catford, Phys. Rev. C 43 (1991) 1758.
[7] F. Ajzenberg-Selove, Nucl. Phys. A 490 (1988) 1.
[8] D.R. Tilley, J.H. Kelley, J.L. Godwin, D.J. Millener, J.E. Purcell, C.G. Sheu, H.R. Weller, Nucl. Phys. A 745 (2004) 155.
[9] U.C. Bergmann, M.J.G. Borge, R. Boutami, L.M. Fraile, H.O.U. Fynbo, P. Hornshøj, B. Jonson, K. Markenroth, I. Martel Bravo, I. Mukha, T. Nilsson, G. Nyman, A. Oberstedt, Y. Prezado Alonso, K. Riisager, H. Simon, O. Tengblad, F. Wenander, K. Wilhelmsen Rolander, Nucl. Phys. A 692 (2001) 427.
[10] Y. Prezado, U.C. Bergmann, M.J.G. Borge, J. Cederkäll, C.Aa. Diget, L.M. Fraile, H.O.U. Fynbo, H. Jeppesen, B. Jonson, M. Meister, T. Nilsson, G. Nyman, K. Riisager, O. Tengblad, L. Weissman, K. Wilhelmsen Rolander, Phys. Lett. B 576 (2003) 55.
[11] S. Dixit, et al., Phys. Rev. C 43 (1991) 1758.
[12] L. Buchmann, E. Gete, J.C. Chow, J.D. King, D.F. Measday, Phys. Rev. C 63 (2001) 034303.
[13] K. Sumiyoshi, H. Utsunomiya, S. Goko, T. Kajino, Nucl. Phys. A 709 (2002) 467.
[14] O. Tengblad, U.C. Bergmann, L.M. Fraile, H.O.U. Fynbo, S. Walsh, Nucl. Instrum. Methods A 525 (2004) 458.
[15] H.O.U. Fynbo, M.J.G. Borge, L. Axelsson, J. Äystö, U.C. Bergmann, L.M. Fraile, A. Honkanen, P. Hornshøj, Y. Jading, A. Jokinen, B. Jonson, I. Martel, I. Mukha, T. Nilsson, G. Nyman, M. Oinonen, I. Piqueras, K. Riisager, T. Siiskonen, M.H. Smedberg, O. Tengblad, J. Thaysen, F. Wenander, Nucl. Phys. A 677 (2000) 38.
[16] J. Mösner, G. Schmidt, J. Schintlmeister, Nucl. Phys. 64 (1965) 169.
[17] Y.S. Chen, T.A. Tombrello, R.W. Kavanagh, Nucl. Phys. A 146 (1970) 136.
[18] J.P. Elliot, University of Rochester, NYO-2271, 1958.
[19] F.C. Barker, Nucl. Phys. 83 (1966) 418.
[20] J.C. Adloff, K.H. Souw, C.L. Cocke, Phys. Rev. C 3 (1971) 1808.
[21] M. Langevin, C. Détraz, F. Naulin, M. Epherre, R. Klapisch, S.K.T. Mark M. de Saint Simon, C. Thibault, F. Touchard, Nucl. Phys. A 366 (1981) 449.
[22] G. Nyman, et al., Nucl. Phys. A 510 (1990) 189.
[23] P.R. Christensen, C.L. Cocke, Nucl. Phys. 89 (1966) 656.
[24] L.C. Biederharn, M.E. Rose, Rev. Mod. Phys. 25 (1953) 729.
[25] L.J. Bever, Ph.D. Thesis, Utrecht, 1993.
[26] O.V. Bochkarev, Yu.O. Vasil'ev, A.A. Korsheninnikov, E.A. Kuz'min, I.G. Mukha, V.M. Pugach, L.V. Chulkov, G.B. Yan'kov, Sov. J. Nucl. Phys. 52 (1990) 964.
[27] D.J. Millener, private communication.
[28] N. Kumar, Nucl. Phys. A 225 (1974) 221.